

The University of Chicago

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A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS

1940

By

E. G. EBBIGHAUSEN

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INTRODUCTION

The primary purpose of this investigation is the determination of the relative proper motions in four galactic clusters, as follows: NGC 752, NGC 2548, M 67, and M 39. The details of the method of determining these proper motions are given in the discussion of NGC 752.

After the proper motions have been determined, the following problems are open to solution: (1) the separation of the cluster members from the field stars within the limits of error of the motions; (2) the purification of the spectrum-magnitude diagram of the cluster; (3) the determination of the luminosity function of the cluster; and (4) the determination of the absolute proper motion of the cluster. Problem 1 is considered to have been solved with a considerable degree of success for the first three clusters but to a much smaller degree for M 39.

The solution of the remaining three problems depends on how well the first problem was solved. The separation of cluster members from field stars is, however, a necessary but not a sufficient condition for the determination of the absolute proper motion of the cluster. The latter can be determined by either one or both of the following methods: (1) If a sufficient number of field stars are available, the absolute proper motion can be determined by adding to the parallax motion of the field stars the relative proper motion of the field stars with respect to the cluster stars. (2) A number of stars in the cluster must have known meridian proper motions. The first method resulted in a fairly accurate determination of the absolute proper motions of NGC 752 and M 67 but not for the other two clusters. M 39 is the only cluster for which stars were found in the *General Catalogue*; but, since it is not known if these stars belong to the cluster, its absolute proper motion is unknown.



PROPER MOTIONS IN THE GALACTIC CLUSTER NGC 752

E. G. EBBIGHAUSEN

ABSTRACT

Proper motions are derived on Allegheny plates for an area of about 50' diameter centered on the cluster NGC 752. The results are contained in Tables 3 and 4; plots of the motions are found in Figures 1*A* and 1*B*. The positions of the probable cluster members are found in Figures 2*A* and 2*B*. The spectral diagram of the probable cluster members, Figure 3*B*, has reduced the cluster to a narrow sequence. The luminosity function is found in Figure 4.

This paper gives the results of the determination of proper motions in the cluster NGC 752 ($\alpha = 1^h51^m8$, $\delta = +37^\circ11'$, 1900). Other clusters will be discussed in subsequent papers. NGC 752 was considered an important object for proper-motion studies because of the exceptional character of its spectral diagram. Since no suitable first-epoch plates of NGC 752 were available at the Yerkes Observatory, the writer gratefully appreciates the co-operation of the Allegheny Observatory in supplying the plate material. The first-epoch plates were taken during the years 1915-1918 by Dr. R. J. Trumpler, who called the writer's attention to the existence of these plates. The second-epoch plates were kindly taken by Dr. Keivin Burns.

I. THE MATERIAL

The material available for measurement consisted of five pairs of plates whose average interval was 20.9 years. Three of these pairs had only one image of each star, while one pair had three images and another five images of each star. Table 1 is a list of these plates.

II. MEASUREMENT AND REDUCTION

The procedure adopted in this paper was to obtain for each old plate a new plate taken with the same center but exposed through the glass in order that the two plates could be placed film to film and the measurement done differentially. In the measuring machine each pair of plates was firmly held in contact by means of six clamps, which also held the pair in contact with two sheets of clear glass in

order to form a firm foundation. As is usually done, the x - and y -co-ordinates were made to correspond, respectively, with right ascension and declination.

The measuring device was a micrometer eyepiece fitted with a fixed and a movable wire. The power used was 27. The whole assembly could be rotated in order that the measurements could be made in four position angles, 90° apart. Each pair of plates was first placed in the machine with the north edge upward. For each pair of images the differences, Δx and Δy , were measured in both the direct and reverse directions. After this had been done for all the stars on

TABLE 1

Old Plate	New Plate	Interval in Years	No. of Images	Limiting Magnitudes	Symbol
3695.....	56014	22.1	1	14.0	P I
7497.....	55992	21.1	1	12.2	P V
7408.....	55993	21.1	1	12.1	P VI
7578.....	55877	21.0	5	12.4	P VII
14321.....	55944	19.1	3	12.5, 12.3, 11.9	P II, P III, P IV

the pair of plates, the pair was turned 90° , with the north edge to the right; and the same procedure of measurement was again followed. This procedure resulted in the measurement of four values of each of the differences, Δx and Δy , which were averaged to form a mean value of each difference, $\overline{\Delta x}$ and $\overline{\Delta y}$, for each star. The reductions were carried out with the aid of the linear formula

$$\overline{\Delta x} = ax + by + c$$

for the x -co-ordinate and a similar one for the y -co-ordinate. No fewer than fifty stars were ever used in the least-squares solution for the reduction constants. In order to select stars of small motion for the comparison stars, one pair of plates was first reduced, using all the stars as comparison stars and then discarding those stars of large motion. For that pair the reduction was again performed with the reduced number of stars, and for each succeeding pair of plates as many of the same comparison stars were used as possible.

Then for each star the computed values of differences, Δx_c and

Δy_c , were obtained; and the proper motion in both co-ordinates was derived by forming the differences

$$\overline{\Delta x} - \Delta x_c = \mu_x,$$

$$\overline{\Delta y} - \Delta y_c = \mu_y.$$

With the aid of the scale value (1 mm = 14".6) and the interval in years the values of μ_x and μ_y were converted into units of ten-thousandths of a second of arc per year.

All of the material was divided into seven groups and designated as P I, P II, . . . , P VII. P I, P V, and P VI refer to pairs of plates with one exposure on each. P II, P III, and P IV refer to three sets of images of different exposure times on the same pair of plates. P VII refers to the pair of plates with five exposures each. Instead of treating each set of images as a separate plate, the twenty measured values of Δx and of Δy on P VII were averaged to form a mean value of each difference, and the reductions were carried out, treating the five sets of images as one plate.

When, as in the case of NGC 752, the proper motion of the cluster relative to the noncluster stars is small, the problem of separating the cluster and the noncluster stars requires a high accuracy. The following sources of error are of importance: (1) errors of measurement, (2) differential refraction between the two plates if the plates are taken at different hour angles, (3) shifting of the emulsion, (4) error in the micrometer screw, (5) errors due to changes of temperature during the measurement of the plates, and (6) the magnitude equation. The first source can be reduced in size by measuring several pairs of plates and by measuring the images in both the direct and the reversed directions. The second can be largely eliminated by using the same kind of emulsion for both the old and the new plates and by taking the new plate at the same hour angle as the old plate. The shifting of the emulsion can be minimized by exercising care in the development and the drying of the plates. Errors due to (4) and (5) may be largely eliminated by placing the two plates film to film and making differential measurements. In this fashion the length of the micrometer screw used is always less than 1 mm.

The magnitude equation may be classed as a systematic error, since it superimposes on the proper motion of a star a spurious motion which is a function of the magnitude. This magnitude equation can be evaluated if a number of cluster stars of different magnitude are known. In order to select these stars in a provisional way, the motions derived from P VII were plotted. Near the origin of this plot was found an isolated, elongated group of stars which could be expected to contain a large percentage of cluster stars. Of this group, thirty stars were selected as probably belonging to the cluster. The magnitudes of these stars were then plotted against the values of μ_x and μ_y , respectively, and a straight line was drawn through the mean position of the points on each plot. The value of the magnitude equation for both the x - and y -co-ordinates was then applied to all of the stars on P VII, and a plot of these motions was again made. In this diagram the isolated group was much smaller and was almost circularly symmetrical. From this group the thirty stars lying closest to the center of gravity were used to remove the magnitude equation from all the remaining plates, P I to P VI. The average magnitude equation found from the seven different sets amounted to about $0''.005/\text{yr}/\text{mag}$. In order to find whether any magnitude equation remained in the various plates, the differences P I — P VII, P II — P VII, . . . , P VI — P VII, were formed for all stars in common to each individual set. When these differences were plotted against magnitude, no residual magnitude equation with respect to P VII was found, except in two cases, where it was small but large enough to be applied. These differences also indicated any systematic differences with respect to P VII, owing to the use of slightly different sets of comparison stars; and, if present, they were applied.

The motions from the various plates were now in a form which would permit them to be combined after the weights of the individual plates P I to P VII had been determined. In order to determine these weights, the differences P I — P VII, . . . , P VI — P VII, were again formed. Each group of differences was divided into three subgroups, depending on whether the star belonged to the brightest, the intermediate, or the faintest stars on the plate. For each subgroup the quantity $\Sigma v^2/n - 1 = (\text{m.e.})^2$ was formed.

For each group P I — P VII, , P VI — P VII, it was found that the value of the mean error as determined for each co-ordinate and for each magnitude subgroup did not vary sufficiently from the mean of the six values to be considered significant. Hence, the mean value of the mean error was adopted, and no distinction was made as to the co-ordinate or the magnitude group. The actual determination of the weights requires one more set of differences, and these were taken between the two most accurate pairs, namely, P V and P VI. The resulting values of (m.e.)² were then reduced to relative weights, which are given in Table 2.

TABLE 2

Plate	Wt.	Plate	Wt.
P I.....	1.0	P V.....	2.0
P II.....	0.5	P VI.....	2.0
P III.....	1.0	P VII.....	5.5
P IV.....	1.5		

With the aid of these weights the motions derived from the various plates were combined and are given in Table 3. The columns give, respectively:

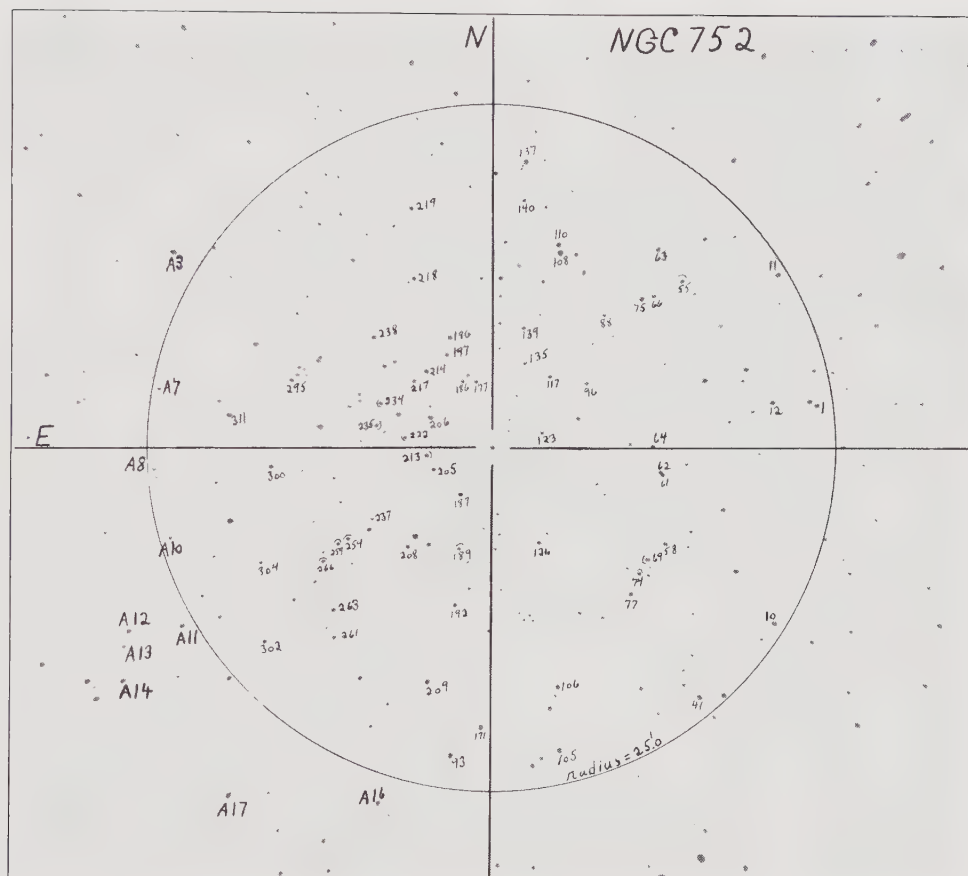
1. The number according to Heinemann's *Catalogue*.¹
2. The photographic magnitude in Trumpler's system.² For the stars having a spectral type given in the third column, magnitudes were kindly supplied by Dr. R. J. Trumpler. For the other stars Heinemann's magnitudes were used, reduced to Trumpler's system by the writer.
3. The spectral type, kindly communicated by Dr. R. J. Trumpler.
- 4 and 5. The proper motions in x and y expressed in units of $0''.0001/\text{year}$.
6. The weights of the motions in the preceding columns. Unit weight corresponds to a mean error of $\pm 0''.0033$, as obtained from the internal agreement between the plates. A dot used as a superscript indicates that the given weight p is really $p + \frac{1}{2}$.

¹ *A.N.*, 227, 213, 1926.² Private communication.

TABLE 3

Star	m_{pg}	Spec.	$\mu_a \cos \delta$	μ_δ	Wt.	Member- ship
I.....	10.3	.....	- 30	- 23	2	2
3.....	10.4	.....	- 39	- 8	2	3
10.....	10.5	.....	- 15	+ 3	4	2
11.....	10.0	.....	- 24	+ 17	4	2
12.....	10.2	.....	- 21	- 37	9*	2
21.....	12.2	.....	-216	+ 53	7	4
24.....	9.9	.....	- 44	- 24	12*	3
27.....	10.0	.....	- 66	- 11	12*	4
32.....	10.1	.....	-113	- 39	7*	4
34.....	10.1	.....	- 41	- 9	13*	3
39.....	8.9	gG9	-187	+ 2	11*	4
40.....	11.4	.....	- 50	+118	5	4
41.....	10.1	.....	- 25	+ 6	8	2
51.....	12.5	.....	-150	+130	7	4
55.....	11.6	.....	- 30	+ 15	10	2
58.....	10.6	F ₃	0	- 25	12*	1
61.....	10.2	F ₅	- 6	- 4	13	1
62.....	11.6	F ₃	- 9	- 13	13*	1
63.....	11.4	.....	- 10	- 30	4	2
64.....	10.6	.....	+ 3	+ 9	13*	1
66.....	11.0	F ₃	- 2	- 9	13*	1
68.....	12.3	.....	-104	+ 81	3*	4
69.....	10.4	F ₃	+ 22	- 6	13*	1
73.....	11.4	.....	- 86	+ 76	12*	4
74.....	11.0	F ₂	- 6	+ 1	13*	1
75.....	9.8	gK ₂	- 24	+ 7	13*	2
77.....	10.0	gG8	- 30	+ 1	13*	2
78.....	12.1	Go	-467	-320	8	4
88.....	12.2	F ₃	+ 23	- 15	10	1
91.....	12.3	K	+ 45	+141	1*	4
96.....	10.3	F ₂	+ 10	- 6	13*	1
99.....	12.1	Ao	- 65	+160	8	4
101.....	11.9	.....	+496	- 25	12	4
102b.....	10.0	F ₃	-235	- 54	13*	4
102ft.....	11.6	.....	-237	- 59	11*	4
103.....	12.1	Ko	- 94	+162	6	4
105.....	10.4	.....	- 10	+ 32	13*	2
106.....	10.6	.....	- 18	+ 1	13*	1
108.....	9.4	F ₂	- 32	- 7	8	2
110.....	9.7	gG ₂	- 11	- 11	5	2
114.....	10.9	.....	- 85	+ 48	13*	4
117.....	10.5	F ₃	+ 11	- 2	11*	1
120.....	12.6	.....	+ 53	- 19	6	3
123.....	11.4	Fo	+ 16	- 2	10*	1
124n.....	11.9	.....	- 13	+130	1*	4

PLATE XXIII



FINDER CHART FOR NGC 752

The circle has a radius of 25' with star No. 166 as center. The numbers which are not preceded by *A* refer to stars whose membership class is either 1 or 2. Those numbers which are preceded by *A* refer to stars which were measured but had no Heinemann number.

TABLE 3—*Continued*

Star	m_{pg}	Spec.	$\mu_\alpha \cos \delta$	μ_δ	Wt.	Member- ship
1248.....	11.9	.....	+ 32	+120	1*	4
126.....	10.3	F ₄	+ 10	- 4	13	1
129.....	11.0	.....	+ 17	+ 42	12*	3
132.....	12.8	.....	-113	+ 41	1*	4
135.....	11.5	F ₂	+ 8	+ 2	13*	1
137.....	9.9	.....	- 3	- 35	2	2
139.....	12.1	F ₃	+ 16	+ 12	10	1
140.....	12.0	.....	+ 3	- 43	3	2
159.....	9.7	F ₅	- 41	+ 7	10*	3
161.....	12.5	.....	+ 54	+ 25	7*	3
163.....	12.7	.....	+ 74	+ 50	2	3
165.....	11.3	.....	-152	+ 62	2	4
166.....	10.1	F ₂	- 28	+ 25	13*	3
171.....	10.4	.....	0	+ 24	11*	2
177.....	10.5	F ₆	+ 42	- 12	12	2
185.....	12.6	.....	+ 53	- 67	1*	3
186.....	11.0	gK ₀	- 2	+ 6	8	2
187.....	10.7	F ₂	+ 13	- 5	13*	1
189.....	11.5	F ₂	- 10	0	13*	1
192.....	10.8	F ₃	+ 2	- 22	12*	1
193.....	10.2	.....	- 17	+ 2	12*	1
196.....	10.5	F ₅	+ 13	- 2	13*	1
197.....	11.9	F ₃	+ 17	+ 11	13*	1
205.....	10.2	F ₂	+ 3	- 18	13*	1
206.....	10.4	F ₅	+ 5	- 12	13*	1
208.....	9.9	gG ₉	- 18	- 12	12	1
209.....	9.5	.....	- 27	- 6	13*	2
213.....	10.0	.....	- 16	- 13	13*	1
214.....	10.7	F ₂	+ 32	- 15	13*	2
215.....	8.2	gK ₃	- 21	-181	6*	4
217.....	10.7	F ₃	+ 3	- 7	13*	1
218.....	10.3	.....	+ 6	- 20	13*	1
219.....	10.7	.....	+ 28	- 26	5	2
220.....	10.5	gK ₀	+287	-330	11*	4
222.....	11.3	F ₃	+ 6	- 6	13*	1
225.....	10.6	F ₈	-114	+139	13*	4
226.....	12.7	G ₀	+110	- 35	7	4
232.....	12.0	F ₄	+ 52	- 17	12	3
234.....	11.0	F ₂	+ 36	- 4	13*	2
235.....	11.7	F ₆	+ 4	- 4	13*	1
237.....	12.6	.....	+ 24	- 12	1*	2
238.....	10.2	F ₂	+ 11	- 12	13*	1
240.....	10.1	F ₆	-303	-177	13*	4
246.....	10.6	.....	+147	-671	13*	4
250.....	12.0	F ₁	+ 55	+ 23	12	4

TABLE 3—*Continued*

Star	m_{pg}	Spec.	$\mu_{\alpha} \cos \delta$	μ_{δ}	Wt.	Member- ship
253.....	12.4	.....	- 67	-580	1*	4
254.....	11.1	F ₃	- 3	- 21	11*	1
255.....	12.8	F ₉	+200	-142	1*	4
258.....	12.5	F ₉	+ 11	- 55	7	3
259.....	11.6	F ₄	+ 23	- 15	13*	1
260.....	12.3	.....	-169	+110	3	4
261.....	11.4	.....	+ 10	- 23	13*	1
263.....	11.0	.....	0	- 12	13*	1
264.....	12.4	F ₅	+ 8	+ 48	7	3
266.....	11.5	F ₅	+ 13	- 27	13*	1
271.....	9.3	F ₂	-143	-133	13*	4
272.....	12.9	.....	- 22	+126	1*	4
273.....	11.7	F ₅	+ 9	+ 59	13*	4
275.....	12.5	.....	+ 50	- 80	1*	3
293.....	12.2	.....	+ 39	- 38	10	3
295.....	10.0	gKo	- 1	- 18	13*	1
300.....	9.8	F ₂	- 1	- 16	13*	1
302.....	11.6	.....	+ 9	- 28	13*	1
304.....	12.2	.....	+ 31	- 12	10	2
306.....	10.7	.....	-103	+ 68	13*	4
308.....	11.1	.....	-239	+ 85	13*	4
309.....	8.2	.....	-242	- 28	3	4
311.....	9.9	.....	- 7	- 18	13*	1
314.....	11.9	.....	+116	- 54	10	4
316.....	12.3	.....	- 2	+108	1*	4
319.....	12.4	.....	- 24	+128	1*	4
A ₃	9.2	.....	- 55	- 28	3	3
A ₇	12.3	.....	+228	-422	10	4
A ₈	12.6	.....	+ 34	- 66	1*	3
A ₁₀	12.4	.....	+210	-326	1*	4
A ₁₁	11.6	.....	- 65	+ 91	13*	4
A ₁₂	12.3	.....	- 80	+128	1*	4
A ₁₄	11.6	.....	- 82	+ 4	3	3
A ₁₆	10.6	.....	+ 4	- 31	8*	2
A ₁₇	10.2	.....	+ 37	- 50	8*	3

7. A measure of the probability that the star is a member of the cluster. The figure 1 indicates that the star has a high probability of being a cluster member; 2 indicates that the probability is lower but that the star has a reasonable chance of being a member; 3 denotes that the star is probably not a member; and 4 signifies that the star is definitely not a cluster member. The assignment of membership will be discussed in Section III.

The plates had roughly the same limiting magnitude, except P I, which went down to 14.0. Since the faint stars on this pair of plates could not be measured on any other pair, their motions have a rather small accuracy. The magnitude equation for these stars was obtained by simply extrapolating the straight line indicated by the brighter stars on the same plate. These stars are given in Table 4, where column 1 gives Heinemann's number, column 2 gives Heinemann's photographic magnitude, and columns 3 and 4 list the proper motions in x and y in units of $0''.0001/\text{year}$.

III. DISCUSSION OF THE RESULTS

The data given in Table 3 are complete down to about $m_{\text{pg}} = 12.2$, within a radius of $25'$ of star No. 166, which is the origin of the co-ordinates given by Heinemann. This does not, however, apply to a small portion of the northernmost part of the cluster, which was not covered by the plates. The spectra given by Trumpler are complete down to $m_{\text{pg}} = 10.7$, but only three stars brighter than 12.5 have not been classified. These stars with spectra all lie within a radius of $16'.7$ ($1000''$) of star No. 166.

The weights assigned to the individual stars range from 1.5 to 13.5. A weight of 13.5 corresponds to a mean error of $\pm 0''.0009/\text{year}$ in either co-ordinate. Figure 1A is a plot of all stars having a weight $p > 10$. Figure 1B is a plot of all stars with $p \leq 10$. The stars with a weight of $9\frac{1}{2}$ and 10 are indicated by circles crossed with a horizontal line. Stars with $5 \leq p \leq 8\frac{1}{2}$ are circles, and those with $p < 4$ are plain dots.

The assignment of probability of membership in the cluster was made in the following manner. The average weight of the stars in Figure 1A corresponds to a mean error of $\pm 0''.0010/\text{year}$. Three circles were drawn with their centers at the center of gravity of the concentration. The radii of these circles are 2.5, 4.0, and 6.0 times the mean error just given. Stars falling within the inner circle were assigned to class 1; stars between the first and second circles were assigned to class 2; those between the second and third circles, to class 3; and those outside the third circle, to class 4.

The stars in Figure 1B were divided into three groups: (1) $p = 9\frac{1}{2}$ and 10, (2) $5 \leq p \leq 8\frac{1}{2}$, and (3) $p < 4$. No stars had a weight of $4\frac{1}{2}$ or 9. The mean errors corresponding to the average weight of the

TABLE 4

No.	m_{pg}	$\mu_a \cos \delta$	μ_δ	No.	m_{pg}	$\mu_a \cos \delta$	μ_δ
8.....	13.7	- 16	+ 20	170.....	13.3	- 6	+174
16.....	12.8	- 39	+ 20	175.....	13.5	+296	+101
20.....	13.3	+ 23	+130	176.....	12.3	+ 81	- 63
26.....	12.4	- 13	+ 18	182.....	12.6	+ 63	- 52
28.....	12.9	+ 80	+128	184.....	12.8	+ 52	+ 52
30.....	12.4	-120	+ 76	190.....	14.0	- 46	+107
36.....	13.4	-142	+ 40	207.....	13.7	+ 93	- 2
37.....	12.4	+ 2	+ 10	221.....	13.6	- 3	+133
44.....	13.3	+124	-101	228.....	12.7	-233	+150
45.....	13.1	+ 26	+189	229.....	12.9	+ 42	+ 40
48.....	12.6	+ 34	- 44	230.....	13.9	+ 23	+ 68
49.....	13.2	- 67	+110	231.....	13.2	- 39	+122
50.....	13.4	- 33	+ 76	236.....	12.8	+ 24	- 11
52.....	12.9	+237	+146	244.....	13.1	+ 42	+ 42
56.....	13.7	+ 55	- 52	248.....	13.1	+ 76	+ 67
59.....	13.3	- 52	+179	249.....	13.2	- 6	+ 78
65.....	13.9	- 67	+ 5	251.....	14.0	+ 57	- 66
67.....	13.8	- 2	+ 78	252.....	13.2	+ 31	+ 44
71.....	14.0	+ 28	+117	256.....	13.7	+ 37	+ 83
76.....	13.8	- 59	+ 63	265.....	13.6	+ 60	0
80.....	13.2	+ 50	- 34	267.....	13.5	-107	+ 88
86.....	12.0	- 72	+ 54	269.....	14.0	+ 2	+143
87.....	13.0	+ 98	- 18	274.....	11.8	- 20	+ 80
92.....	13.0	+ 37	+150	276.....	14.3	+ 33	+107
95.....	13.6	+ 57	+125	277.....	13.0	- 23	+ 18
98.....	14.0	- 63	+133	280.....	14.0	-201	+135
100.....	13.5	+ 16	+ 70	281.....	13.0	-132	+ 62
104.....	13.1	- 6	+106	282.....	13.4	- 50	+ 90
107.....	13.6	+100	- 13	283.....	14.2	- 13	+107
109.....	13.3	- 81	+ 99	284.....	12.5	- 57	+ 99
112.....	13.0	- 60	+150	285.....	13.7	+ 13	+ 44
118.....	12.7	- 30	+190	286.....	13.7	+190	+660
121.....	12.7	+ 21	+179	287.....	13.1	- 80	+156
128.....	13.6	+ 44	+109	289.....	12.4	- 80	- 28
130.....	13.2	-111	+ 86	290.....	13.3	- 85	+174
141.....	13.8	- 57	+132	291.....	12.8	+ 37	+ 76
144.....	13.4	- 80	+ 81	292.....	12.5	- 37	+ 24
145.....	13.0	- 20	+ 89	297.....	14.1	+298	+ 34
146.....	13.5	+ 83	0	299.....	12.7	- 34	+ 72
148.....	14.1	- 73	+ 68	301.....	13.8	- 37	+ 38
149.....	14.2	0	+283	313.....	13.5	+ 86	+ 5
151.....	12.6	+ 73	+ 5	318.....	12.8	76	+166
154.....	13.6	- 20	+ 57	318.....	13.0	47	+135
157.....	12.8	+ 20	+ 8	A13.....	11.6	- 20	+ 50
160.....	12.8	+ 2	+ 83				
162.....	13.3	- 6	+ 94				
164.....	12.8	- 15	+ 67				
167.....	13.4	+ 80	+ 8				
168.....	13.2	-100	+118				

three groups are $\pm 0''.0011/\text{year}$, $\pm 0''.0013/\text{year}$, and $\pm 0''.0023/\text{year}$, respectively. For the first group the radii of the three circles were taken to be 2.5, 4.0, and 6.0 times the mean error, as was done for the stars of Figure 1*A*. The membership classes were made in the same manner. For the second and third groups, no class 1 membership was given. The adopted radii for the second group are 2.5 and 5.0 times the average mean error; and for the third group, 2.5 and 4.0 times the average mean error. In both cases stars falling within

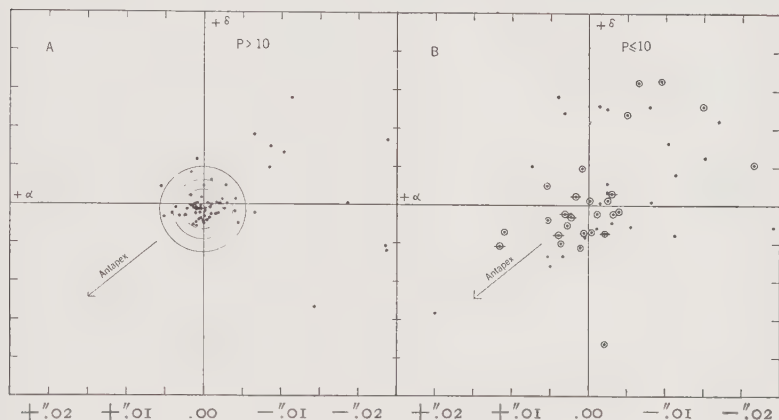


FIG. 1

the inner circle were given class 2 membership. The number of stars which were rated as belonging to classes 1 and 2 is 62.

Figure 2*A* is a plot of the positions in the cluster of all stars whose weights are > 10 , and Figure 2*B* gives the positions of all stars whose weights are ≤ 10 . In both plots the circled dots are those with a cluster membership of class 1 or class 2. It will be noticed that the cluster members do not show any marked concentration toward the center in the region discussed. The concentration of the stars in Figure 2*B* toward the outer regions of the cluster is largely due to the fact that not all of the plates had the same center.

Of considerable interest are Figures 3*A* and 3*B*, which show the spectrum-magnitude diagram. Figure 3*A* is the same as that published by Kuiper in his discussion of the hydrogen content of clusters;³ it contains all the stars with known spectra. The ordi-

³ *Ap. J.*, 86, 176, 1937.

nates are apparent bolometric magnitudes, and the abscissas are $\log T_e$. The same temperature scale was used as in Kuiper's paper.

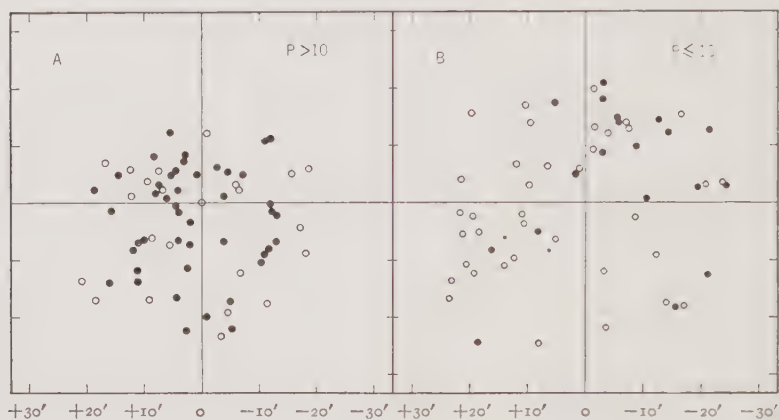


FIG. 2

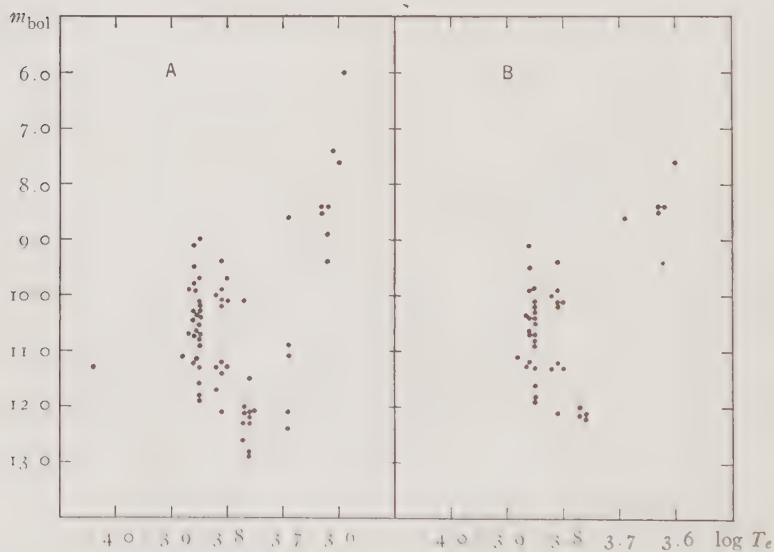


FIG. 3

In Figure 3B only stars with a cluster membership of 1 or 2 have been included. The striking difference between the two figures is im-

mediately evident. It is of interest to note that the brightest star in the cluster, No. 215, is probably not a cluster member, although this conclusion is rendered somewhat uncertain because the magnitude equation for this star had to be extrapolated.

It is of interest to use the preceding results in the study of the luminosity function of the cluster. The data suffice for the derivation of this function for photographic magnitudes. The result is given in Figure 4. The maximum around $m_{pg} = 10.2$, and the relatively small number of faint cluster members are noteworthy. The

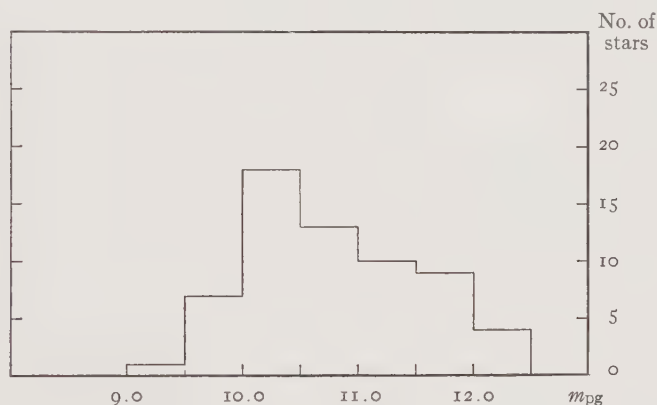


FIG. 4.—Luminosity function for NGC 752

distance modulus of NGC 752 is about 8.0. Hence the absolute photographic magnitude of the maximum is about $+2.2$, which differs greatly from that found for stars in general and for other galactic clusters.

IV. THE ABSOLUTE PROPER MOTION OF THE CLUSTER

Unfortunately, no cluster members are contained in the *Boss General Catalogue*. In Schorr's *Eigenbewegungs Lexikon* motions are given for 14 cluster members. The proper motion of the cluster derived from these stars is $\mu_{\alpha} \cos \delta = +0''.005/\text{year} \pm 0''.004$ (m.e.) and $\mu_{\delta} = -0''.010/\text{year} \pm 0''.005$ (m.e.), or $0''.011/\text{year} \pm 0''.005$ (m.e.) in position angle about 158° . As a result of the rather large mean error of this determination, the value is not very significant.

An attempt was then made to determine the absolute motion from

the measures of the faint stars on P I. The proper motion of the cluster relative to 55 stars between photographic magnitude 13.0 and 13.9, inclusive, was found to be $\mu_a \cos \delta = +0''.002/\text{year}$ and $\mu_\delta = -0''.009/\text{year}$. In this mean, two stars of exceptionally large motion were omitted (Nos. 175 and 286 in Table 4). If these two stars are included, the motion of the cluster becomes $\mu_a \cos \delta = 0''.000/\text{year}$ and $\mu_\delta = -0''.011/\text{year}$. For stars of mean photographic magnitude equal to 13.5 and at 23° from the galactic plane Oort gives⁴ the mean parallax as $0''.0017$. The antapex is 90° from the cluster in position angle 129° . The galactic co-ordinates of the cluster are $l = 105.4$ and $b = -22.7$; and at this position the galactic rotation effect is about $-0''.003$ in galactic longitude, or very nearly $\mu_a \cos \delta = -0''.003/\text{year}$. Hence, the absolute proper motion of the cluster becomes $0''.012/\text{year}$ in about 160° , which happens to agree very well with the value determined from meridian positions. The motion of the cluster, omitting the galactic rotation term, is about $0''.014$ in 147° , but most of this is the reflex of the solar motion, which is $0''.010$ in 129° . Therefore, corrected for solar motion, the true transverse motion of the cluster is about 10 km/sec .

Grateful acknowledgment is made to Dr. R. J. Trumpler and Dr. K. Burns, who have taken the first- and second-epoch plates, respectively. The writer wishes to express his sincere thanks to Director Jordan for having made the plate material available. The writer is further indebted to Dr. Trumpler for his permission to use his spectral types for this cluster. I wish to express my thanks to Dr. Kuiper for having suggested this problem and for his general guidance.

YERKES OBSERVATORY

December 1938

⁴ *B.A.N.*, 8, 90, Fig. 3, 1936.

PROPER MOTIONS IN THE GALACTIC CLUSTER NGC 2548

E. G. EBBIGHAUSEN

ABSTRACT

Proper motions are derived on Yerkes plates for an area 30' in diameter centered on the cluster NGC 2548. The results are contained in Table 2. Plots of the motions are found in Figure 1, *A* and *B*. The positions of the probable cluster members are found in Figure 2, *A* and *B*. Figure 3 is the spectrum-magnitude diagram of the cluster. The luminosity function of the cluster is given in Figure 4.

This paper gives the results of the determination of proper motions in the cluster NGC 2548 ($\alpha = 8^{\text{h}}08^{\text{m}}08^{\text{s}}$, $\delta = -5^{\circ}30'$, 1900; $l = 196^{\circ}$, $b = +17^{\circ}$). For this cluster Dr. R. J. Trumpler gives a distance of 470 parsecs, a diameter of 30', and the type is designated as 1-2*a*, indicating that a small number of giant stars may belong to the cluster. Verification of the membership of these giants is one of the main objects of this paper.

I. THE MATERIAL

The material available for measurement consisted of four pairs of plates, taken with the 40-inch refractor of the Yerkes Observatory, each pair having only one image. Table 1 gives a list of these plates.

TABLE 1
THE MATERIAL

Old Plate	New Plate	Interval in Years	Limiting Photovisual Magnitude	Symbol
F 120.....	F 500	27.9	12.5	P I
F 176.....	F 499	24.9	12.0	P II
II 3048.....	F 498	21.0	11.6	P III
II 3095.....	F 595	21.8	12.0	P IV

II. MEASUREMENT AND REDUCTION

The procedure adopted in this paper is the same as that used in the measurement and reduction of the material for NGC 752.¹ Brief-

¹ *Ap. J.*, **89**, 431, 1939.

ly, that procedure is as follows: Each old plate was matched by a new plate taken through the glass. The two plates were placed film to film, and the measurements of Δx and Δy were made in both the direct and the reversed directions. The measured values of the differences were then averaged for each star, to form a mean value for both Δx and Δy . The measuring device was the same as that used for NGC 752. The reduction constants were obtained by a least-squares solution of the formula

$$\overline{\Delta x} = ax + by + c,$$

with a similar formula for the y -co-ordinate.

In order to select the stars of small motion for the least-squares solution, a preliminary reduction was first made for P I, the plate with the faintest limiting magnitude. Of the 114 stars on this plate, 76 were selected as comparison stars; for the remainder of the pairs—P II, P III, and P IV—the comparison stars were always taken from this group. The smallest number of comparison stars used was 38 for P III.

Then for each plate and each star the computed values of the differences (Δx_c and Δy_c) were obtained, and the proper motion in both co-ordinates (μ_x and μ_y) resulted from the difference between the observed and the computed value of each difference. With the aid of the scale value (1 mm = 10".6) and the interval in years, the values of μ_x and μ_y were converted into units of ten-thousandths of a second of arc per year.

In order to select cluster stars for the elimination of the magnitude equation, the measures of all stars common to all four plates were averaged and plotted. The resulting plot indicated a very distinct concentration of stars near the origin, and from these stars 41 were selected as provisional cluster stars. The plate and filter combination used for the plates of this cluster give magnitudes very nearly on the photovisual system; but since no photovisual magnitudes were available, the measured diameters were used in the reductions. Subsequently, these diameters were converted into approximate photovisual magnitudes by means of the A-type stars

and their photographic magnitudes. For only two plates, P I μ_δ and P III μ_δ , was any magnitude equation detectable.

After the magnitude equation had been removed, the material was ready for the determination of the weights of the individual plates. Again the same plan was followed as in the case of NGC 752. The differences P I — P II, P I — P III, P I — P IV, and P II — P IV were formed for both μ_x and μ_y . Each set of differences for each plate was divided into three subgroups, depending on photovisual magnitude. These groups were 8^m5–9^m5, 9^m6–11^m2, and 11^m3–12^m2. Then, for each of the twenty-four subgroups the quantity $\Sigma v^2/n - 1$ was formed. None of these values of the mean error differed significantly from the mean to indicate a real difference; as a consequence no distinction in weight was made with reference to image diameter, and each plate was given unit weight.

With the aid of these weights the motions from the various plates were combined and are given in Table 2. The columns give, respectively:

1. The author's catalogue number (no previous catalogue has been published).

2 and 3. The co-ordinates, on a system in which $+x$ and $+y$ indicate increasing right ascension and declination, respectively. One unit = 8".6.

4. The photographic magnitude in Trumpler's system.² Most of the magnitudes were kindly supplied by Dr. R. J. Trumpler in advance of publication. For the remainder, interpolations were made on an Eastman 40 plate of the cluster taken with the 24-inch reflector of the Yerkes Observatory. For a few faint stars a slight extrapolation was necessary.

5. The spectral type, kindly communicated by Trumpler.² A dash in place of the spectral type indicates that Trumpler supplied the magnitude but gave no spectral type.

6 and 7. The proper motions in x and y expressed in units of 0".0001/year.

8. The weight of the motions in columns 6 and 7. Unit weight corresponds to a mean error of $\pm 0".0024$ as obtained from the inter-

² Private communication.

TABLE 2
THE CATALOGUE

No.	x	y	m_{pg}	Spec.	μ_x	μ_y	Wt.	Member- ship
1.....	230	82	10.4	.....	+ 3	+ 5	4	1
2.....	246	103	8.9	.....	+ 7	- 85	4	4
3.....	215	116	9.9	.....	+ 25	- 81	4	4
4.....	243	117	11.6	.....	+ 4	+ 20	3	1
5.....	225	123	10.7	.....	+ 9	+ 16	4	1
6.....	231	126	11.5	.....	- 16	+ 1	4	1
7.....	219	183	11.6	.....	- 30	- 18	4	3
8.....	191	66	9.0	gG5	- 18	+ 4	4	1
9.....	199	112	11.0	A	+ 9	+ 6	4	1
10.....	194	118	12.3	—	+ 4	+ 2	2	2
11.....	205	126	10.9	.....	- 22	+ 10	3	2
12.....	207	132	10.7	.....	- 63	+ 22	4	4
13.....	188	141	9.0	A2	- 6	+ 23	4	1
14.....	200	148	11.5	.....	- 13	+ 22	3	2
15.....	210	148	10.0	.....	- 13	- 8	4	1
16.....	196	164	10.4	.....	- 16	- 10	4	1
17.....	166	46	10.4	Ao	+ 11	+ 6	4	1
18.....	172	48	10.8	Ao	+ 12	+ 12	4	1
19.....	171	60	12.8	.....	- 119	- 20	1	4
20.....	182	63	12.5	.....	- 17	- 7	2	2
21.....	167	90	11.5	Go	- 152	+ 48	4	4
22.....	165	116	12.4	.....	- 21	+ 8	2	2
23.....	173	121	12.2	—	+ 22	+ 7	2	2
24.....	177	133	12.7	.....	- 74	+ 3	1	3
25.....	176	144	11.3	A	- 9	+ 12	4	1
26.....	178	139	12.3	.....	+ 14	- 63	1	3
27.....	166	151	10.0	B8	- 3	- 1	4	1
28.....	182	205	9.2	.....	+ 86	+ 69	4	4
29.....	152	32	9.9	A2	- 5	- 3	3	1
30.....	154	38	11.4	—	- 238	+ 129	4	4
31.....	158	44	12.3	.....	- 41	- 49	1	3
32.....	159	55	11.6	—	+ 13	+ 2	2	2
33.....	140	57	12.3	.....	+ 1	- 626	3	4
34.....	148	63	10.7	A3	+ 14	- 7	4	1
35.....	161	70	11.5	Ko	- 11	- 71	4	4
36.....	154	83	11.5	A	+ 4	0	3	1
37.....	160	89	10.7	A2	+ 7	+ 2	4	1
38.....	162	94	11.0	—	+ 21	+ 19	3	2
39.....	150	98	12.2	—	- 75	- 13	3	4
40.....	154	106	11.6	A3:	+ 2	- 6	3	1
41.....	157	106	10.6	A2	+ 8	0	4	1
42.....	142	119	12.5	.....	+ 5	- 28	3	2
43.....	140	121	11.5	A5	+ 30	+ 10	3	2
44*.....	138	129	8.8	A2	—	+ 13	2	1
45.....	142	133	9.7	A1	+ 22	+ 14	4	1

* No. 44: double star, brighter preceding component.

TABLE 2—*Continued*

No.	x	y	m_{pg}	Spec.	μ_x	μ_y	Wt.	Member- ship
46.....	148	132	11.6	A:	— 5	— 7	3	I
47.....	149	144	9.2	A1	+ 4	+ 11	4	I
48.....	159	143	12.5	.....	— 66	+ 19	1	3
49.....	160	151	11.5	—	— 2	+ 1	3	I
50.....	161	178	12.4	.....	— 56	— 53	1	3
51.....	156	180	11.7	—	+ 16	— 10	3	I
52.....	139	181	8.7	A1	+ 2	+ 10	4	I
53.....	118	48	12.0	—	— 144	+ 18	3	4
54.....	121	50	11.6	A5:	+ 18	— 34	3	3
55.....	118	54	11.9	—	— 21	0	4	I
56.....	127	63	11.7	A2	+ 14	— 5	3	I
57.....	116	68	11.4	A5	+ 9	+ 4	2	2
58.....	119	72	10.2	G8	— 1	— 15	3	I
59.....	128	77	12.2	A:	+ 19	— 45	1	3
60.....	121	84	12.4	K:	+ 29	— 37	4	3
61.....	129	87	10.9	A1	— 1	— 17	4	I
62.....	116	96	12.4	—	+ 15	— 85	2	3
63.....	113	97	12.6	—	+ 10	— 16	1	2
64.....	120	103	12.7	K:	— 24	+ 54	2	3
65.....	134	102	8.9	A1	+ 14	+ 2	4	I
66.....	135	107	9.9	gGo	+ 1	— 4	4	I
67.....	126	113	9.7	A3	+ 16	— 5	4	I
68.....	128	115	10.9	A3	+ 25	— 5	4	I
69†.....	127	118	9.1	F2p	— 14	— 10	4	I
70.....	132	122	11.0	A	+ 5	— 14	3	I
71.....	132	122	10.5	A	+ 1	+ 14	3	I
72.....	137	121	10.1	A2	— 14	+ 8	4	I
73.....	134	135	12.5	.....	+ 60	— 92	1	4
74.....	111	138	12.5	—	— 34	— 24	1	3
75.....	127	147	10.0	A2	+ 7	0	4	I
76.....	132	152	9.9	A0	— 12	+ 8	4	I
77.....	131	192	10.4	—	+ 15	+ 5	4	I
78.....	114	197	12.4	.....	— 10	— 69	1	3
79.....	131	232	12.2	.....	— 43	— 67	1	4
80.....	98	92	11.4	A3	+ 10	— 12	3	I
81.....	104	94	9.8	A1	+ 18	+ 4	4	I
82.....	107	105	9.3	A1	+ 10	+ 16	4	I
83.....	97	125	9.6	A1	— 11	— 1	4	I
84.....	99	126	12.5	.....	— 159	— 58	1	4
85.....	99	132	12.0	—	+ 31	— 5	3	2
86.....	103	146	10.9	Go	— 238	— 110	4	4
87.....	103	147	12.4	—	— 235	— 111	3	4
88.....	87	154	10.5	A:	+ 29	— 7	4	2
89.....	104	161	12.8	.....	— 180	— 158	1	4
90.....	87	174	8.4	A1	— 11	+ 6	4	I

† No. 69: according to Trumpler, the F2p spectrum is probably composite A+G.

TABLE 2—Continued

No.	x	y	m_{pg}	Spec.	μ_x	μ_y	Wt.	Member- ship
91.....	97	192	12.7	.....	- 7	+ 1	1	2
92.....	103	201	12.0	.....	- 9	- 20	2	2
93.....	106	205	12.3	.....	+ 78	- 39	1	4
94.....	90	207	10.5	.....	- 8	+ 17	4	1
95†.....	90	209	8.8	A1	+ 8	- 13	4	1
96.....	87	220	10.9	.....	+ 1	+ 13	2	2
97.....	104	220	12.0	.....	+ 40	- 3	1	2
98.....	82	46	10.6	A0	+ 4	- 19	4	1
99.....	66	71	9.8	A2	- 8	- 4	4	1
100.....	78	116	10.1	A2	+ 12	- 9	4	1
101.....	64	128	9.2	A1	+ 15	- 27	4	2
102.....	67	155	12.0	—	- 80	- 142	2	4
103.....	71	172	9.1	A1	- 2	- 6	4	1
104.....	68	185	11.9	.....	+ 10	+ 6	2	2
105.....	80	212	11.0	.....	+ 45	- 93	2	4
106.....	37	66	10.7	.....	- 36	- 9	4	3
107.....	54	85	11.2	A2	+ 12	- 5	4	1
108.....	42	86	10.7	.....	+ 59	- 21	4	4
109.....	31	106	11.7	.....	+ 73	- 104	2	4
110.....	49	127	11.7	.....	+ 10	- 93	3	4
111.....	47	157	11.8	.....	+ 18	- 17	3	1
112.....	59	191	12.4	.....	+ 13	+ 59	1	3
113.....	59	191	12.4	.....	+ 20	+ 92	1	4
114.....	51	194	10.9	.....	- 86	- 45	4	4
115.....	53	202	9.3	.....	+ 10	+ 5	2	2

† No. 95: double star, north following component.

nal agreement between the plates. A number of faint stars on P I did not occur on any of the other three plates; and, although no direct determination of their weight could be made, it was considered reasonable to give them the same weight as the remainder of the stars on P I, i.e., unit weight.

9. A measure of the probability that the star is a cluster member. The figure 1 indicates that the star has a high probability of being a cluster member; 2 indicates that the probability is lower but that the star has a reasonable chance of being a member; 3 indicates that the star is probably not a member; and 4 signifies that the star is definitely not a cluster member. This assignment of membership will be discussed in the next section.

III. DISCUSSION OF THE RESULTS

The data given in Table 2 are complete down to photovisual magnitude 12.0, within a radius of $15'$ of star No. 72. As a result of the close proximity of the image of a fainter star to the image of No. 44, it was possible to measure its motion only in the y -direction. As a result of its motion ($\mu_\delta = 0''.0013/\text{year}$) and its position in the spectrum-magnitude diagram ($\log T_e = 4.04$ and $m_{\text{bol}} = 8.2$), No. 44 may provisionally be considered as being a cluster member.

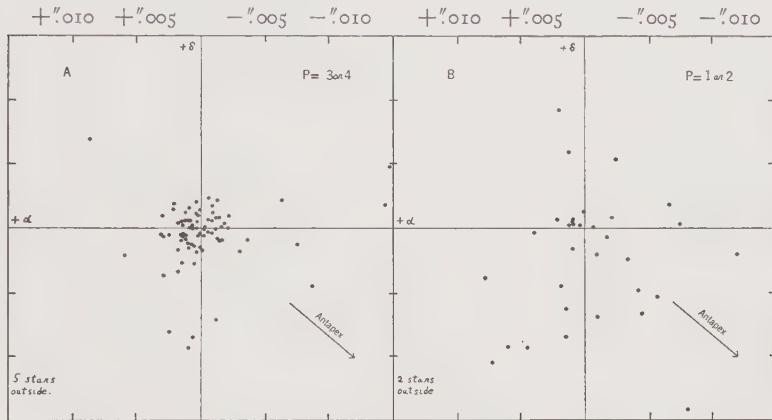


FIG. 1

The weights assigned to the individual stars range from 1 to 4. A weight of 4 corresponds to a mean error of $\pm 0''.0012/\text{year}$ in either co-ordinate. Figure 1, A, is a plot of all stars with weight of 3 or 4, and in Figure 1, B, are plotted all stars with weight 1 or 2.

The determination of the probability of membership in the cluster was made in the following manner. The average weight of the stars in Figure 1, A, corresponds to a mean error of $\pm 0''.0013/\text{year}$. Three circles, of radii 2, $2\sqrt{2}$, and 4 times the mean error just given, were drawn with their centers at the center of gravity of the concentration. Stars within the first circle were assigned to class 1, stars between the first and second circles to class 2, those between the second and third circles to class 3, and the stars outside of the third circle to class 4.

The average weight of the stars in Figure 1, *B*, corresponds to a mean error of $\pm 0''.0021$ /year. About the center of gravity two circles

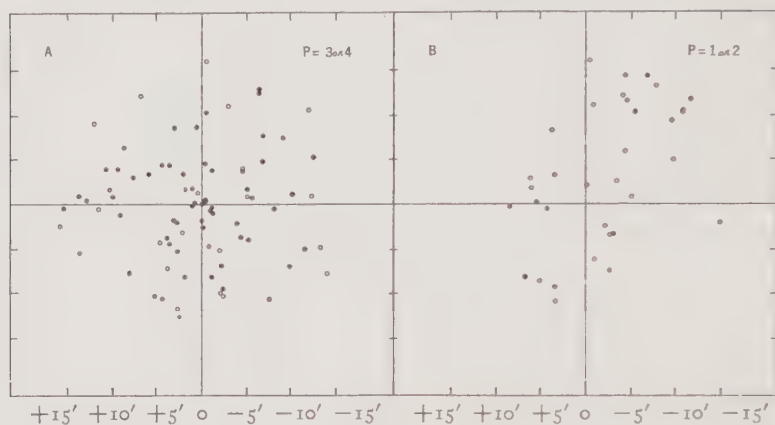


FIG. 2

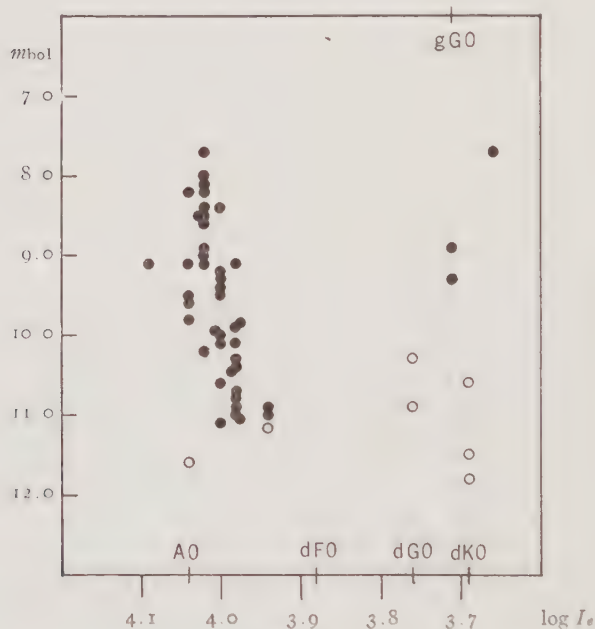


FIG. 3

were drawn with radii 2 and 4 times this mean error. No class-1 membership was assigned to any star in this group. Class-2 mem-

bership was assigned to the stars inside the first circle, and class-4 membership to those outside the second circle.

The number of stars with a membership class of 1 or 2 is 74.

Figure 2, *A*, is a plot of the position in the cluster of all stars whose weight is either 3 or 4, and Figure 2, *B*, is a plot of all whose weight is either 1 or 2. In both figures the filled circles correspond to stars with a class membership of 1 or 2.

Figure 3 is a plot of the spectrum-magnitude diagram. The filled circles represent stars with a membership class of 1 or 2, and the open circles are those of class 3 or 4. The abscissas are $\log T_e$, and

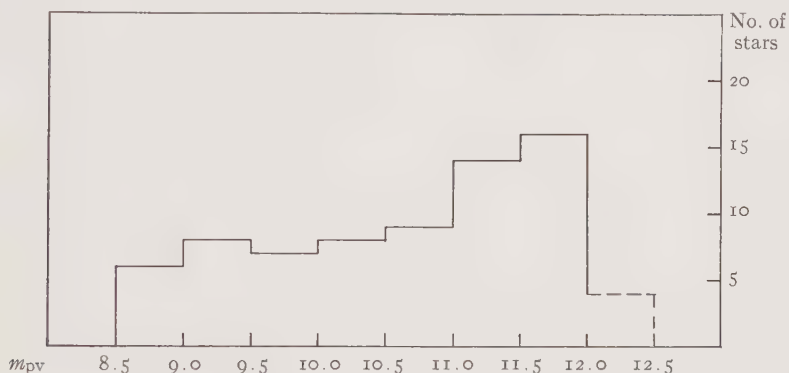


FIG. 4.—Luminosity function for the cluster members

the ordinates are apparent bolometric magnitudes. The reduction of Trumpler's spectra and photographic magnitudes to this new system was carried out with the aid of the table given by Kuiper in his discussion of the hydrogen content of clusters.³

Figure 4 gives the luminosity function of the cluster with the photovisual magnitude as the abscissa. The diagram is complete for the area with a radius of $15'$ around star 72 and down to about $m_{pv} = 12.0$. The distance modulus of NGC 2548 is about 8^m6 .⁴

IV. THE PROPER MOTION OF THE CLUSTER

Since there are only a few faint stars in the cluster, and because none of the measured stars occur in either the *Boss General Catalogue* or Schorr's *Eigenbewegungs Lexikon*, no attempt has been made to determine the absolute proper motion of the cluster.

³ *Ap. J.*, **86**, 176, 1937.

⁴ Trumpler, *Lick Obs. Bull.*, No. 420, 157, 1930.

The writer wishes to express his sincere thanks to Dr. Trumpler for having communicated in advance of publication his spectral types and magnitudes for this cluster. Grateful acknowledgment is made to Dr. Struve for having enabled the writer to continue this investigation after he had left the Yerkes Observatory to teach at Wilson College. Also, I wish to express my thanks to Dr. Kuiper for his general guidance.

YERKES OBSERVATORY

June 1939

PROPER MOTIONS IN THE GALACTIC CLUSTER M 67

E. G. EBBIGHAUSEN

ABSTRACT

Proper motions are derived on Yerkes plates for an area 30' in diameter centered on the cluster M 67. The results are contained in Table 2. Plots of the motions are given in Figures 1, *A* and 1, *B*, and the position of the cluster members in the cluster in Figures 2, *A* and 2, *B*. Figure 3 gives the spectrum-magnitude diagram of the cluster, and Figure 4 the luminosity function of the cluster members.

This paper gives the results of the determinations of proper motions in the galactic cluster M 67 ($\alpha = 8^h45^m8$; $\delta = +12^\circ11'$; $l = 184^\circ$; $b = +33^\circ$). For this cluster Trumpler gives 2-3a as its type, meaning that the cluster has many giants and that the upper limit of the main sequence is at spectral type A. For M 67 he gives 740 parsecs as its distance and 16' as its apparent diameter. Because of its large distance from the galactic plane (+406 parsecs) and the large number of late-type giants, the cluster is of considerable interest.

Previous work on the cluster has been done by Olsson at Stockholm in 1898¹ by Fagerholm,² Shapley,³ and van Rhijn.⁴ The results of these papers will be discussed later when the occasion demands.

I. THE MATERIAL

The material consisted of four pairs of plates, each pair having only one image of each star. Table 1 is a list of these plates. I wish

TABLE 1

Old Plate	New Plate	Interval in Years	Limiting pv Magnitudes	Symbol
F 179.....	F 599	26.1	13.0	P I
F 174.....	F 600 A	26.1	13.0	P II
F 305.....	F 597 A	17.0	12.3	P III
Sch 241.....	F 601 A	35.0	11.7	P IV

to express my thanks to Dr. J. Titus and Dr. C. Hetzler for having taken these plates in my absence.

¹ *Pub. Stockholm Obs.*, 6, No. 4, 1898.

³ *Mt. W. Contr.*, No. 117, 1916.

² *Diss. Upsala*, 1906.

⁴ *Groningen Pub.*, No. 33, 1922.

II. MEASUREMENT AND REDUCTION

The procedure adopted in this paper is the same as that used in the author's paper⁵ on the galactic cluster NGC 752, where it is fully described. The only difference in procedure is that the measurements were made only with the north edge upward and not again with the same edge to the right. This resulted in two measures of Δx and two of Δy , which were then averaged to form for each star a mean value $\overline{\Delta x}$ and $\overline{\Delta y}$. A least-squares solution using a linear formula was then made for each set of differences (Δx and Δy), using all the stars on P I. With the aid of the resulting constants, the motions μ_x and μ_y were derived. The stars of large motion were removed, and the differences ($\overline{\Delta x}$ and $\overline{\Delta y}$) of the remaining stars were used in a final solution of the reduction constants and in the derivation of the motions of the stars on P I. These comparison stars were used whenever possible on the remaining three plates.

The removal of the magnitude equation was accomplished in the following manner: For all stars common to all four plates the motions in the x - and y -directions were averaged and then plotted. From the resulting concentration near the origin, a number of stars closest to the center of gravity were taken as being cluster stars. Then for each plate the individual values of μ_x and μ_y were plotted against the magnitude, and through the points on each plot a straight line was drawn. For five of the resulting eight plots the line had an appreciable slope, and the average value of the magnitude equation so derived was about $0''.0025/\text{year mag.}$ The magnitude equation for the stars on P I and P II fainter than 11.7 was obtained by extrapolating the straight line defined by the brighter stars.

After the motions from the four plates had been corrected, they were then in a form to permit them to be combined after the weights of the individual plates had been determined. In order to do this the differences P I - P II, P I - P III, P II - P III, P III - P IV were formed for all stars common to all four plates and for the motions in both x and y . Each of the eight groups of differences was divided into two subgroups according to whether the star was brighter than or fainter than $m_{pv} = 11.2$. Then, for each of the sixteen subgroups the quantity $\Sigma v^2/(n - 1)$ was formed. For none of the sub-

⁵ *A p. J.*, **89**, 431, 1939.

TABLE 2

Star No.	m_{pv}	Spec.	μ_x	μ_y	Wt.	Membership
2.....	13.1	.....	+ 52	- 19	1	3
3.....	12.7	.....	-116	0	2	4
4.....	12.7	.....	- 21	+ 14	2	2
5.....	12.9	.....	+ 20	+ 15	1	2
6.....	12.7	.....	- 30	- 8	2	2
8.....	12.4	.....	- 28	+ 48	2	3
12.....	13.0	.....	+ 27	- 9	1	2
16.....	12.6	.....	- 19	- 2	2	2
18.....	12.8	.....	+ 14	+ 44	2	3
20.....	12.8	.....	- 12	+ 3	2	2
22.....	12.8	.....	+ 20	+ 30	2	2
23.....	12.4	.....	- 86	+145	2	4
24.....	13.0	.....	- 17	- 51	1	3
28.....	12.8	.....	- 10	- 2	2	2
29.....	13.2	.....	+ 70	- 36	1	3
30.....	12.0	F2	- 20	+ 3	3	1
34.....	13.0	.....	+ 37	- 15	1	2
36.....	13.2	.....	+ 68	- 35	1	3
37.....	12.7	.....	+ 39	+ 33	2	3
39.....	13.1	.....	+ 28	+ 29	1	2
41.....	13.1	.....	+ 50	+ 31	1	3
44.....	13.1	.....	- 22	- 28	2	2
45.....	13.0	.....	+ 45	- 61	2	3
46.....	13.0	.....	+ 32	+ 18	2	2
47.....	11.5	.....	+126	-198	3	4
48.....	12.7	.....	+ 41	- 6	2	2
49.....	12.6	.....	+ 96	+ 36	2	4
51.....	12.7	Go	- 20	- 17	2	2
53.....	13.2	.....	+ 38	- 4	1	2
54.....	12.7	.....	0	- 15	2	2
55.....	11.6	A4	+ 46	+ 7	4	3
56.....	13.2	.....	+ 99	- 13	1	4
65.....	12.8	F4	+ 16	- 29	2	2
68.....	13.2	.....	+129	+ 75	1	4
69.....	13.2	.....	- 67	- 34	1	3
70.....	11.7	F2	+102	+ 56	3	4
72.....	12.4	K:	- 24	+ 1	1	4
78.....	13.3	.....	+ 75	+ 20	1	3
78.....	13.0	.....	+104	+ 6	1	4
79.....	12.6	.....	- 12	- 46	2	3
81.....	10.2	B9	0	+ 18	4	1
83.....	13.0	.....	+ 31	- 29	1	2
84.....	10.6	gK1	+ 10	- 8	4	1
88.....	12.4	Go	- 4	- 12	2	2
90a.....	11.2	F3	+ 2	+ 25	4	1

TABLE 2—*Continued*

Star No.	m_{pV}	Spec.	μ_x	μ_y	Wt.	Membership
90 β	12.5	.....	+ 1	— 10	1	2
91.....	12.7	F2:	+ 42	— 30	2	3
92a.....	12.3	.....	+ 14	+ 27	2	2
94.....	12.7	F8:	+ 24	+ 18	2	2
95.....	12.8	F2	0	+ 11	2	2
96.....	12.6	F8	+ 29	+ 3	2	2
98.....	12.7	F5	+ 3	— 3	2	2
101.....	12.9	.....	+ 17	+ 25	1	2
102.....	12.4	.....	— 16	— 17	2	2
104.....	11.4	gG5	+ 4	— 19	3	1
105.....	10.4	gKo	— 5	— 6	4	1
108.....	9.9	gK3	— 1	+ 8	4	1
111.....	12.6	.....	— 4	— 11	2	2
112.....	13.0	.....	+ 20	— 6	1	2
115.....	12.7	F6	— 1	— 4	2	2
116.....	12.9	.....	+ 10	— 22	1	2
117.....	12.6	.....	+ 22	+ 3	2	2
119.....	12.8	F8	0	+ 28	2	2
124.....	12.2	F1	— 2	+ 28	3	1
127.....	12.7	.....	— 10	— 25	2	2
128.....	13.0	.....	— 39	— 34	2	3
130.....	12.9	G:	+ 20	— 9	2	2
131.....	11.3	F1	+ 19	0	4	1
132.....	13.1	G:	— 16	— 27	2	2
134.....	12.3	F5	+ 22	— 1	3	1
135.....	11.5	gKo	+ 18	+ 36	3	2
136.....	11.4	F9	+ 18	— 4	4	1
141.....	10.4	gKo	— 13	+ 9	4	1
143.....	11.6	gG8	+ 7	— 10	4	1
144.....	12.9	.....	+ 82	— 2	2	3
145.....	12.8	Go:	— 12	— 10	2	2
147.....	13.0	Go:	+ 22	— 32	2	2
148.....	13.0	Go	+ 22	+ 20	2	2
149.....	12.7	F5	+ 16	+ 4	2	2
151.....	10.6	G9	+ 18	+ 4	4	1
153.....	11.5	A3	— 9	— 2	4	1
155.....	10.5	gGo	— 49	+ 7	4	3
156.....	11.2	A1	+ 16	— 12	4	1
157.....	12.7	F8	+ 14	— 4	2	2
160.....	12.8	.....	— 7	+ 158	2	4
161.....	12.8	F3	+ 10	+ 20	2	2
162.....	12.8	F8	+ 4	+ 32	2	2
163.....	12.7	Go	+ 6	— 31	1	2
164.....	10.8	gG9	+ 16	— 7	4	1
165.....	12.7	F5	+ 53	— 12	2	3

TABLE 2—*Continued*

Star No.	m_{pv}	Spec.	μ_x	μ_y	Wt.	Membership
166.....	12.8	G5	+ 40	- 24	2	2
170.....	9.8	gK2	- 7	+ 2	4	1
171.....	12.9	.....	+ 58	+ 10	1	3
172.....	12.6	.....	+ 6	- 36	2	2
173.....	12.2	F8	+ 28	- 3	3	1
173.....	13.0	.....	+ 36	- 4	2	2
174.....	12.7	F8	+ 39	- 6	2	2
175.....	13.4	G:	+ 31	- 4	1	2
176.....	12.7	F8	+ 25	- 22	2	2
180.....	12.6	F5	- 10	- 22	2	2
181.....	12.8	.....	+ 30	- 10	2	2
182.....	12.7	.....	+ 7	0	2	2
184.....	12.3	F0	- 9	+ 21	3	1
185.....	11.3	A4	+ 9	+ 2	4	1
185.....	12.7	F6	+ 20	- 15	1	2
187.....	13.0	F8	- 17	+ 6	2	2
189.....	12.7	.....	+ 22	- 27	2	2
190.....	11.2	A8	+ 14	- 4	4	1
192.....	12.8	.....	+ 16	0	2	2
193.....	12.3	gG5	+ 34	- 6	2	2
195.....	12.7	G0	+ 42	+ 23	2	2
199.....	13.0	.....	+ 40	- 18	2	3
200.....	11.0	G8	- 172	+ 54	4	4
202.....	12.7	F5	+ 26	+ 36	2	2
203.....	12.9	.....	+ 18	+ 10	2	2
206.....	12.7	.....	- 108	- 20	2	4
207.....	12.3	.....	+ 55	- 12	3	3
210.....	12.3	F8	+ 15	+ 20	3	1
215.....	12.7	F5	+ 26	+ 27	2	2
216.....	12.6	F5	+ 80	- 24	2	3
217.....	11.4	K0	+ 22	+ 18	4	1
217.....	12.2	.....	- 4	+ 11	3	1
218.....	11.7	.....	+ 6	0	4	1
219.....	12.6	.....	+ 60	+ 28	2	3
221.....	12.6	F8	+ 68	- 88	2	4
223.....	10.7	gG8	+ 12	- 7	4	1
224.....	11.1	gK2	- 11	+ 4	3	1
225.....	12.0	.....	+ 10	- 20	2	2
226.....	12.7	G0	+ 1	- 22	2	2
227.....	12.7	G0	+ 27	+ 10	2	2
228.....	12.9	.....	- 0	- 54	1	3
229.....	12.8	F2	+ 150	- 130	2	4
231.....	11.6	gK0	- 6	0	3	1
234.....	11.6	.....	- 27	- 500	3	4
236.....	12.4	G0	+ 43	- 1	1	2

TABLE 2—*Continued*

Star No.	m_{pv}	Spec.	μ_x	μ_y	Wt.	Membership
237.....	12.7	.....	+ 2	+ 27	2	2
238.....	11.2	A3	+ 16	+ 6	4	1
241.....	12.7	.....	+ 28	- 6	2	2
242.....	8.0	gKo	- 60	+ 20	3	4
243.....	12.7	F8	+ 14	+ 2	2	2
244.....	11.0	G6	- 2	+ 3	4	1
248.....	12.3	F2	- 12	0	2	2
255.....	12.7	G0	+ 28	- 6	2	2
256.....	12.6	.....	+ 18	0	2	2
257.....	11.6	F8	- 128	- 366	4	4
261.....	10.7	A3	+ 12	- 78	4	4
262.....	12.7	.....	+ 59	+ 26	1	3
265.....	12.5	F8	- 27	+ 152	3	4
266.....	10.7	gG5	+ 13	- 24	4	1
267.....	12.7	.....	+ 16	+ 62	2	3
269.....	13.0	.....	+ 26	+ 16	1	2
271.....	12.8	.....	+ 33	- 22	2	2
277.....	13.0	.....	+ 74	+ 110	2	4
280.....	11.0	A2	+ 33	+ 34	2	2
281.....	12.9	.....	+ 30	- 6	1	2
285.....	12.5	.....	+ 210	- 86	2	4
286.....	10.7	gG5	+ 21	+ 50	1	3
289.....	12.7	.....	+ 33	+ 3	3	1

groups did this quantity differ significantly from the mean of all, and hence all plates were given unit weight regardless of co-ordinate or magnitude. On this basis a weight of four corresponds to a mean error of $\pm 0''.0012$ /year in either co-ordinate.

With the aid of these weights the motions from the various plates were combined and are given in Table 2.

The columns give, respectively:

1. The number according to Fagerholm's catalogue.² His paper also gives a chart of the cluster.
2. The photovisual magnitude according to Shapley.³ His paper also gives photographic magnitudes.
3. The spectral type, kindly communicated in advance of publication by Dr. R. J. Trumpler.
- 4 and 5. The proper motions in x and y expressed in units of $0''.0001$ /year.

6. The weights of the motions in the preceding columns. Weight 4 corresponds to a mean error of $\pm 0''.0012/\text{year}$.

7. A measure of the probability that a star is a member of the cluster. Unity indicates that the star has a high probability of being a cluster member; 2 indicates that the probability is lower but that the star has a reasonable chance of being a member; 3 signifies that the star is probably not a member; and 4 denotes that it is definitely not a cluster member. The assignment of weights is discussed in section III.

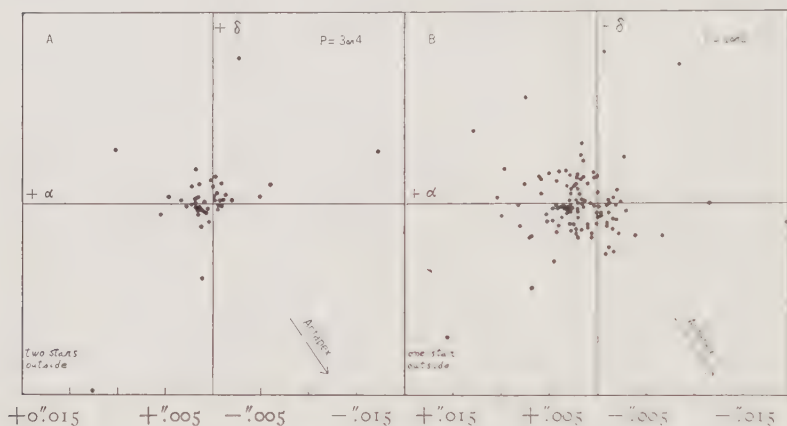


FIG. 1

III. DISCUSSION OF THE RESULTS

The data in Table 2 are complete down to $m_{\text{pv}} = 13.0$, within a radius of $15'$ from star No. 155, which was considered by Shapley to be the center of the cluster.

Figure 1, *A*, is a plot of the motions of the stars with a weight of 3 or 4, and Figure 1, *B*, is a plot of those whose weights are either 1 or 2.

The assignment of probability of cluster membership was made in the following manner: The average weight of the stars in Figure 1, *A*, corresponds to a mean error of $\pm 0''.0014/\text{year}$. About the center of gravity of the concentration three circles were drawn with radii equal to 2, $2\sqrt{2}$, and 4 times the mean error just given. Stars within the smallest circle were given class 1 membership, those between the

first and second circles class 2, those between the second and third circles class 3, and those outside the largest circle class 4. The average weight of the stars in Figure 1, *B*, corresponds to a mean error of $\pm 0''.0021$ /year. In this case the circles were given radii of two and four times the mean error just given, and no class 1 membership was assigned. Those stars within the first circle were given class 2 membership and those outside the second circle class 4.

Figure 2, *A*, gives the position in the cluster of all stars with weights 3 or 4, and Figure 2, *B*, gives the positions of all whose

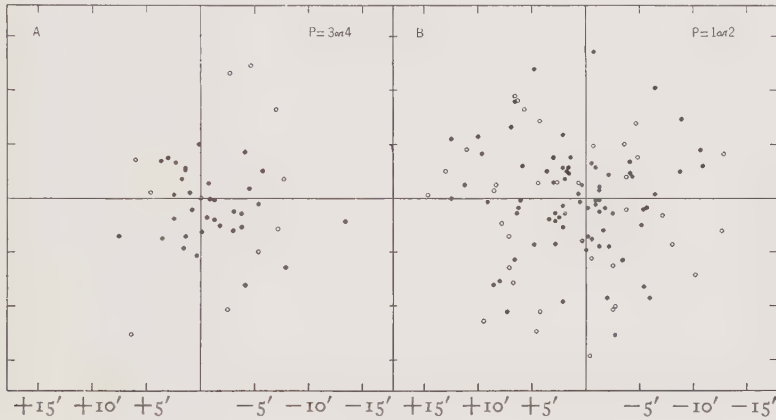


FIG. 2

weights are 1 or 2. In both cases the filled dots correspond to stars whose membership class is 1 or 2.

The appearance of the cluster on a photographic plate is that of a nucleus of bright stars about $16'$ in diameter, superimposed on a background of fainter stars. On P III and P IV only the nucleus of brighter stars was present, while on P I and P II a considerable number of fainter stars outside the nucleus were measured also. For this reason, stars with weight 3 or 4 are concentrated toward the center of the measured area, and stars of weight 1 or 2 are spread over the whole measured area. On the basis of star counts Shapley has found that the cluster of bright stars is "merely a well marked nucleus of brighter and redder stars in a much larger system," which he estimates may extend to a radius of as much as half a degree from

the center. This is the "shoulder" effect which has been found for several clusters by Trumpler.

Figure 3 is the magnitude-spectrum diagram for the cluster. The ordinates are bolometric magnitudes, and the abscissas are given as both $\log Te$ and spectral type. The open circles refer to stars whose

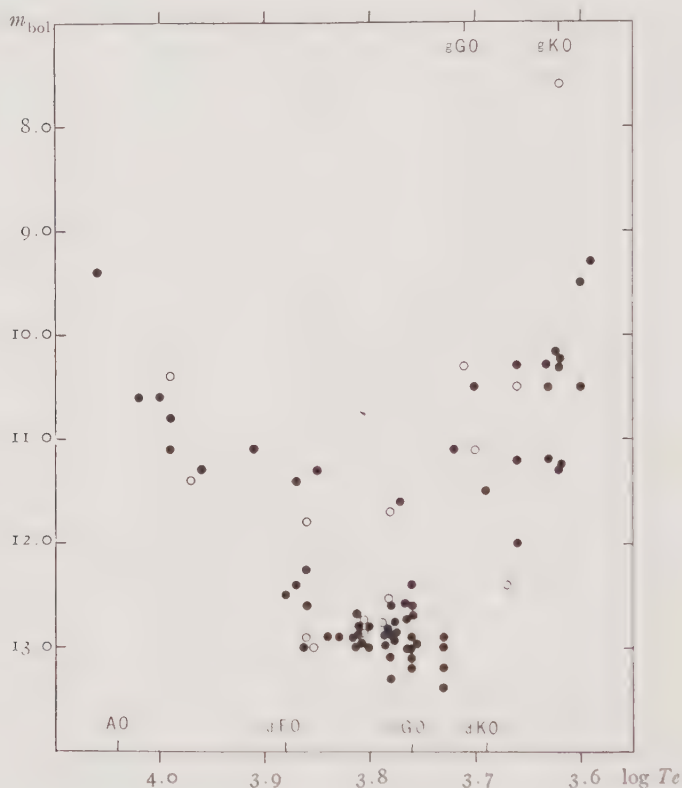


FIG. 3

membership class is 3 or 4. Attention is called to star No. 193, whose position in this diagram is $\log Te = 3.66$ and $m_{bol} = 12$. The distance modulus being 9.3 mag., the star should have an $m_{bol} = +2.7$ which, if the star belongs to the cluster (membership class 2), makes it rather faint for its spectral type, gG5.

The brightest star in the cluster, No. 242, appears not to be a

member. However, since it is 2 mag. brighter than the next faintest star in the cluster, the corrections for magnitude equation had to be extrapolated, and therefore the corrections are very uncertain. The corrected values of motions as derived from the three plates on which the star was measured are quite discordant and their mean cannot be very accurate. Since the magnitude equation is uncertain, it might be better to use the uncorrected values. These happen to be very much more in accord with one another, but their mean still gives

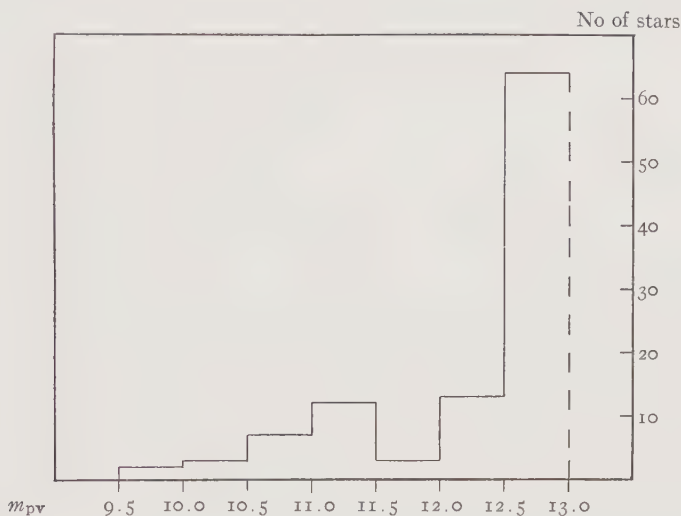


FIG. 4

the star a class membership of 3. The considerable deviation of this star from the center of the cluster ($7'$) might also be considered as evidence that it does not belong to the cluster. The meridian proper motion of this star as derived from only two observations is $\mu_x = -0''.037/\text{year}$ and $\mu_y = -0''.006/\text{year}$.

The spectrum-magnitude diagram of M 67 resembles, to a considerable extent, that obtained for globular clusters, in that a prominent late-type giant sequence is present.

Since the late-type giants have a smaller concentration toward the galactic plane than the B- and O-type stars, those clusters which contain late-type giants might be expected to behave in the same fashion

with respect to clusters that have no such giants but whose brightest stars are of types O, B, and A. To examine this expectation, the galactic clusters in Trumpler's⁶ list were divided into three groups, as follows: first, those whose Trumpler type is 1, i.e., no giants; second, those whose type is 1-2, i.e., uncertainty exists as to whether the giants belong or not; and, third, 2, 2-3, or 3, i.e., giants are certainly members of the cluster. For each of these groups using Trumpler's values for the z -distances the arithmetic mean was formed, and these values together with their standard deviation are for the three groups, respectively, 48 ± 15 , 60 ± 16 , and 102 ± 32 parsecs. In order to avoid selection effects, only clusters between 200 and 1000 parsecs were used in the computation. The run of decreasing concentration toward the galactic plane is in the direction to be expected for early-type and late-type stars not belonging to clusters.

The luminosity function is given in Figure 4. The rapid increase of stars beginning at $m_{pv} = 12.0$ may, to a small extent, be due to the fact that the average motion of the cluster stars differs but little from the mean of the noncluster stars, and some noncluster stars may be included as members. This is partly offset by the fact that some stars which were given class 3 membership may actually belong to class 2.

IV. THE PROPER MOTION OF THE CLUSTER

Two previous attempts have been made to determine the proper motion of the cluster; one by Fagerholm² and the other by van Rhijn.⁴ Fagerholm compared the positions of 118 stars common to his catalogue and that of Olsson's,¹ made eight years before, but found no distinct evidence of motion.

From two *carte du ciel* plates of the cluster with an interval of 27 years, van Rhijn determined the absolute proper motion of the cluster to be $0''.0073/\text{year}$ in position angle 287° . The mean error of an individual star's motion in either co-ordinate is $\pm 0''.009$ year. Although this direction differs by 13° from the direction of the convergent for the Hyades (274°), van Rhijn thought that the two clusters might have the same motion in space. None of the stars measured in the region of M 67 is found in the *Boss General Catalogue*, and only

⁶ *Lick Obs. Bull.*, 14, 154, 1930.

one star, No. 242, is in Schorr's *Eigenbewegungs Lexikon* as mentioned before.

An attempt was made to determine the proper motion from the measures of faint stars in the cluster. The motion of the cluster relative to 29 faint noncluster stars whose mean photographic magnitude is 13.6 was computed to be $\mu_x = -0''.0017 \pm 0''.0014/\text{year}$ and $\mu_y = -0''.0008 \pm 0''.0012/\text{year}$ (m.e.). For stars of $m_{pg} = 13.6$ at galactic latitude $33^\circ.3$, Oort gives a mean parallax of $0''.0021 \pm 0''.0002$ (m.e.), where, because of the few stars used in our case, the mean error is a lower limit. The antapex is 58° from the cluster, in position angle 214° . On the basis of a solar motion of 20 km/sec, the parallactic motion of the group of faint stars used is $0''.0075 \pm 0''.0008/\text{year}$ in position angle 214° . Hence, the proper motion of the cluster so determined is $0''.009 \pm 0''.002/\text{year}$ in position angle $220^\circ \pm 10^\circ$ (m.e.). On the basis of this determination, the difference in direction between the motion of M 67 and the direction of the Hyades convergent is 54° , and hence van Rhijn's suggestion seems improbable.

It is of interest to reinvestigate the space motion of the Praesepe cluster in order to determine whether or not it is parallel to that of the Hyades. Of the stars listed by Klein Wassink⁷ as being members of the Praesepe cluster, 33 were found to have proper motions in the *General Catalogue*. The weighted mean proper motion is $\mu_x = -0''.034 \pm 0''.001/\text{year}$ and $\mu_y = -0''.018 \pm 0''.001/\text{year}$ or a total proper motion of $0''.038 \pm 0''.001/\text{year}$ in $242^\circ.1 \pm 1^\circ.5$. In Moore's catalogue of radial velocities 6 stars were found. Two of these are binaries; for one there is no orbit, and for the other a determination has been made, and hence its space motion is known. The weighted mean of the five determinations of radial velocity is $+33.2 \pm 1.3$ km/sec. The parallax of the cluster as derived by Trumpler is $0''.0067$. On the basis of these data the calculated position of the convergent is $\alpha = 95^\circ.2$ and $\delta = -0^\circ.6$, with a mean error of about one degree in either co-ordinate. The computed space velocity is 42.9 ± 1.5 km/sec. The distance between this convergent and that of the Hyades as determined by Smart⁸ is $9^\circ.5$. An attempt was then made to reduce this distance by changing the adopted parallax of Praesepe.

⁷ *Groningen Pub.*, 41, 1927.

⁸ *M.N.*, 99, 3, 1939.

By changing the parallax to $0''.0072$, the distance between the convergents was reduced to $9^\circ.3$, but no more. Hence it would seem improbable that the magnitude and direction of the space motion of the two clusters is the same.

I wish to express my thanks to Dr. Struve for having placed the facilities of the Yerkes Observatory at my disposal during the summer of 1939 and gratefully to acknowledge the advice which Dr. Kuiper has given to me.

YERKES OBSERVATORY

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PROPER MOTIONS IN THE GALACTIC CLUSTER MESSIER 39

E. G. EBBIGHAUSEN

ABSTRACT

Proper motions are derived from Yerkes plates for an area of about $30'$ diameter centered on the cluster M 39. The resulting motions are contained in Table 2. Plots of the motions are found in Figs. 1, *A* and *B*. The spectral diagram of the cluster is given in Fig. 2.

This paper gives the results of the determination of proper motions in the galactic cluster Messier 39 (NGC 7092; $a = 21^h28^m6$, $\delta = 48^\circ00'$; $l = 60^\circ5$, $b = 2^\circ7$). For this cluster Trumpler gives a distance of 330 parsecs, an angular diameter of $32'$, and the type is

TABLE 1

Old Plate	New Plate	Interval in Years	Limiting Photovisual Magnitude
2656.....	F603	23.0	11.2
2779.....	F604	22.8	11.2

designated as "1a," indicating that the main sequence runs up to spectral type A but that there are no late-type giants. Assuming a distance of 330 parsecs, the distance modulus is 7.6.

Previous work on this cluster has been done by Trumpler,¹ who determined magnitudes, spectral types, and radial velocities for a number of stars. Quite a few of these stars have radial velocities clustering around -14 km/sec, which might be considered to be the radial velocity of the cluster.

The material consists of two pairs of plates taken with the 40-inch refractor of the Yerkes Observatory. Each pair of plates has two images of each star. Table 1 is a list of these plates.

The procedure adopted in this paper is the same as that used in the measurement and reduction of NGC 2548, except that in this

¹ *Pub. A.S.P.*, 40, 265, 1928.

instance the magnitude equation receives a different treatment. Of the total of 50 stars whose motions were measured, 34 were measured in all four sets. The individual motions in both co-ordinates were freed of zero-point differences and averaged to form a mean. These mean motions were then plotted. Near the origin there appeared a fairly loose grouping of stars, from which 24 were selected as provisional cluster members. The individual motions of this group from each set of measures were then plotted against the photo-visual magnitudes. These magnitudes were rough determinations made with the 10-inch Bruce photographic refractor of the Yerkes Observatory, using a I-G plate and a yellow filter with the North Polar Sequence as standard. These plots of motion against magnitude showed such a large scatter that it was considered impossible to determine the magnitude equation and that the provisional cluster members must contain a large percentage of field stars, thereby vitiating the method. It was therefore decided that the published motions should simply be the average of the four sets of measures with zero-point differences removed.

From an intercomparison of the four sets of measures, a mean error of about $\pm 0''.0013$ per year in either co-ordinate was derived for a star which had been measured on all four sets. Because of the difficulties described herein this value of the mean error is necessarily rough. Since no significant difference in weight was found between each of the four sets, unit weight was assumed for each. The combined measures are given in Table 2.

The columns give, respectively:

1. The author's catalogue number (no previous catalogue exists).
- 2 and 3. The co-ordinates on a system in which $+x$ and $+y$ indicate increasing right ascension and declination, respectively. One unit = $22''.6$.
4. The photographic magnitude on Trumpler's system. Most of the magnitudes were kindly supplied by Dr. Trumpler in advance of publication. For the remainder, interpolations were made on an Eastman 40 plate taken with the 24-inch reflector of the Yerkes Observatory.
5. The spectral type kindly supplied by Dr. Trumpler. A dash in

TABLE 2

No.	α	γ	m_{pg}	Spec.	μx	μy	n	Class
1.....	31	160	7.3	Ao	- 24	- 45	4	1
2.....	31	86	10.6	.....	- 36	+ 15	4	2
3.....	44	192	9.1	A1n	+ 7	+ 37	4	1
3a.....	71	226	11.2	A3:	+ 63	+ 334	2	3
4.....	55	180	9.2	A3n	+ 6	+ 8	4	1
5.....	91	172	7.8	A1n	+ 11	- 6	4	1
6.....	64	148	11.5	Fo:	- 16	0	4	1
7.....	90	142	13.0	.....	- 14	+ 79	2	3
8.....	89	140	10.0	A3	- 37	- 46	4	2
9.....	59	137	9.1	G7	+ 131	- 1242	4	3
10.....	61	129	10.9	A3	- 17	- 58	4	2
11.....	87	83	11.2	F3	- 17	- 112	4	3
12.....	83	68	12.1	.....	+ 32	- 2	4	2
13.....	46	63	10.6	.....	+ 23	+ 85	4	3
14.....	46	60	11.5	.....	+ 113	+ 15	4	3
15.....	72	53	12.8	.....	+ 28	- 22	2	2
16.....	97	203	10.3	A4	+ 44	+ 52	4	3
17.....	98	199	7.9	A1n	+ 3	+ 25	4	1
18.....	123	200	12.1	.....	- 1	+ 252	4	3
19.....	129	180	9.0	A2	+ 1	- 2	4	1
20.....	120	178	9.5	A3n	- 21	+ 15	4	1
21.....	132	134	11.2	F8	+ 93	+ 166	4	3
22.....	116	131	8.9	A3s	- 35	- 37	4	1
23.....	112	130	7.6	A1	- 3	- 55	4	1
24.....	130	102	8.0	Aon	+ 164	+ 129	4	3
25.....	105	102	12.0	Ao	+ 102	+ 99	2	3
26.....	110	96	6.8	Aos	- 37	- 100	4	2
27.....	101	77	9.9	A5	+ 180	+ 244	4	3
28.....	105	63	11.3	F2	+ 2	+ 16	3	2
29.....	105	61	12.9	.....	- 9	- 23	3	2
30.....	133	51	8.4	A1	- 85	- 186	2	3
31.....	143	178	8.6	A2n	- 14	- 7	4	1
32.....	146	151	11.8	M3	+ 38	+ 223	4	3
33.....	142	143	6.6	Ao	- 2	- 52	4	1
34.....	137	129	9.6	A2n	- 37	- 30	4	2
35.....	166	130	9.0	A2	- 23	- 65	4	1
36.....	156	113	11.4	Go	+ 293	+ 24	4	3
37.....	147	80	12.2	Ko:	+ 9	+ 68	4	3
38.....	140	78	8.2	Ao	- 42	- 125	4	2
39.....	171	62	9.8	Ko	- 280	- 240	4	3
40.....	170	56	10.7	A1	+ 17	- 36	4	2
40a.....	191	192	6.8	Aos	- 24	+ 57	2	1
41.....	209	44	10.7	.....	+ 83	+ 111	2	3
42.....	191	32	10.1	.....	- 6	+ 0	2	2
43.....	221	129	11.8	.....	- 19	+ 93	2	3
44.....	216	115	11.1	.....	- 46	+ 108	2	3
45.....	233	107	9.1	.....	- 44	- 125	2	2
46.....	239	81	9.1	.....	- 25	- 15	2	1
47.....	230	67	10.1	.....	+ 46	- 16	2	2
48.....	235	57	10.7	.....	- 9	+ 11	2	2

place of the spectral type indicates that Trumpler supplied the magnitude but gave no spectral type.

6 and 7. The proper motions in x and y , respectively, expressed in units of $0''.0001$ per year.

8. The number of times the star was measured.

9. A measure of the probability that the star is a cluster member.

Although the process, described above, of combining the results should, on the average, reduce the magnitude equation, an indeterminate amount remains, and hence the separation of cluster

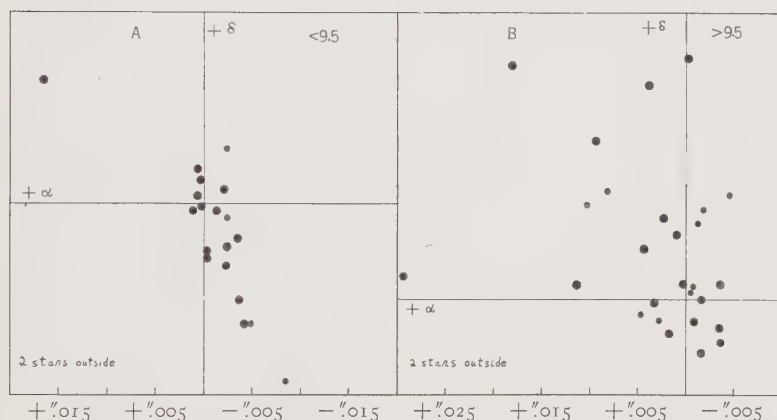


FIG. 1.—Large dots indicate stars measured four times; small dots, twice

members from the field stars will not be as complete as it might otherwise be. A visual inspection of the cluster and the surrounding region indicates that the number of faint cluster members is very small. Figures 1, *A* and *B*, are proper-motion plots for two groups of stars, respectively—those brighter and those fainter than photographic magnitude 9.5. The 14 stars in Figure 1, *A*, near the origin are considered to be cluster stars, and the remainder to be less probable members.

The number of stars brighter than 9.5 mag. and between 9.5 and 11.0 mag., respectively, were counted in the region of the cluster and in a large area surrounding it. It is found that in the cluster 20 stars are brighter than 9.5, whereas the expected number of field stars is 4.5 ± 2 . Hence, 16 ± 2 stars must be cluster members, and 4 ± 2 field

stars. Inspection of Figure 1, *A*, shows a concentration of 14 stars near the origin, and some outlying stars. One is justified, therefore, in identifying the former group as cluster stars, and the designation "class 1" is assigned to them. The three stars just outside this group may, in part, be cluster members, and the designation "class 2" is assigned to them. The remaining 4 stars, of which one is outside

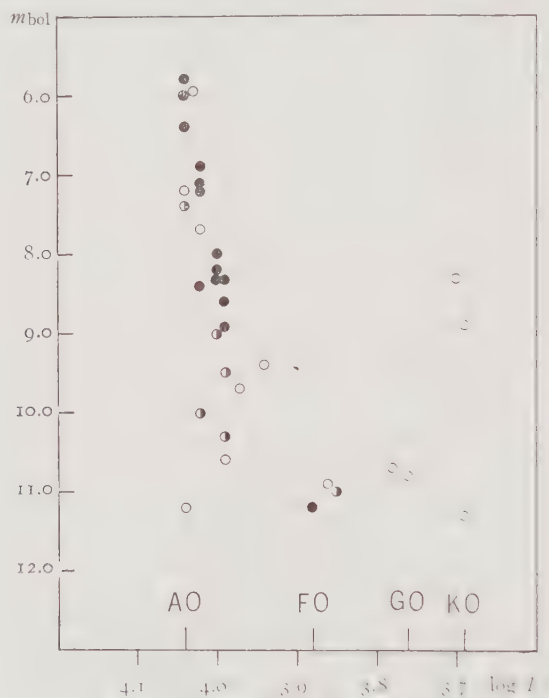


FIG. 2

the diagram, are very probably field stars and are designated as "class 3."

For the stars between photovisual magnitude 9.5 and 11.0 the counts give 32 stars within the cluster area. However, the expected number of field stars is 31 ± 5.5 , so that from the counts alone there is no positive evidence of cluster members fainter than 9.5. Therefore, Figure 1, *B*, must consist largely of field stars, even the inner region. "Class 2" is assigned to the stars of the inner region; and "class 3," to the remainder, which are very probably field stars.

Figure 2 is the spectrum-magnitude diagram of the cluster. The abscissas are given both as $\log T_e$ and spectral type. The ordinates are bolometric magnitudes. The temperature scale is the same as that used in Kuiper's² paper. Class 1 is represented by filled circles; class 2 by half-filled circles; and class 3 by open circles.

Four stars of class 1 are found in the *Boss General Catalogue*. Their weighted mean annual proper motion is $\mu_a = -0''.016 \pm 0''.003$ and $\mu_\delta = -0''.018 \pm 0''.003$, or $0''.024 \pm 0''.003$ in position angle 222° . If all four stars are cluster members, the above value might then be considered as the absolute proper motion of the cluster.

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YERKES OBSERVATORY
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² *Ap. J.*, 86, 176, 1937.

